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NAVAL CONSTRUCTION BATTALION CENTER
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The decision model presented allows a quick estimate of savings-to-investment ratio that may be achieved by burning solid waste to generate utility steam at military bases having 10 to 50 tons per day (9 to 45 Mg/da) of waste fuel. The two types of systems compared use either a rotary grate or a controlled-air furnace for burning the waste fuel.

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INTRODUCTION

It has been known for some time that there exists some potential for saving conventional fuel by utilization of solid waste as a source of energy. To what extent this potential saving could be economically achieved at a broad spectrum of Navy shore facilities is as yet rather poorly defined. Several Navy facilities have recently been surveyed under outside contract. One objective of this report is to supplement part of the contract effort by adding impetus to collection or refinement of waste generation data and various cost data at many facilities. The economic decision model and other information presented herein will assist in the preliminary survey and cost evaluation of most bases with less refuse than 50 tons per day (TPD) (45 Mg/da) for potential utilization of refuse fuel energy for generation of utility steam. The decision model is a supplement to the Navy's Recovery and Reuse of Refuse Resources (R^4) Program.

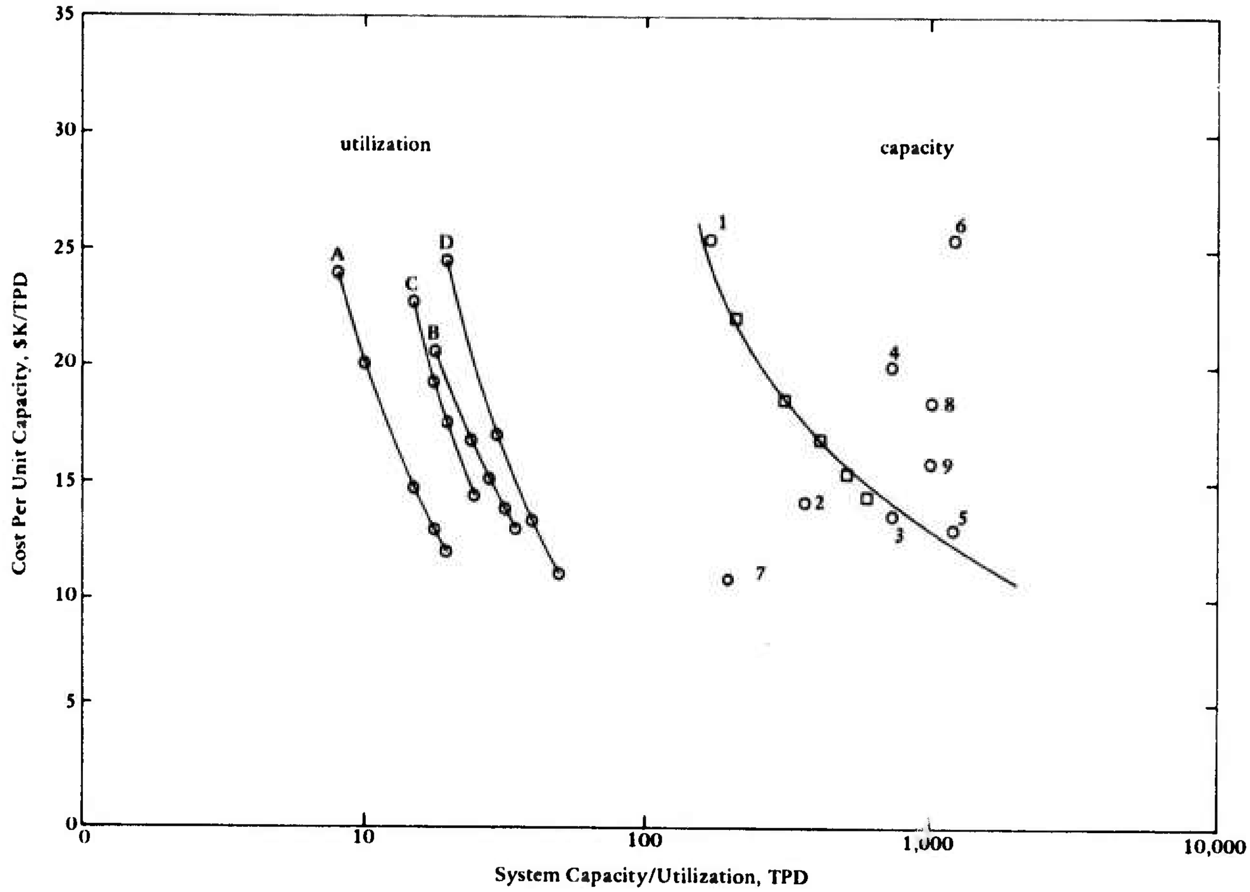
The systems modeled are intended for evaluation for near-future implementation. Four points should be emphasized: (1) the model is for preliminary decisions only, (2) an alternative method for disposal of solid waste must be retained for periods of down time, (3) none of the systems discussed are yet procurable as fully standardized and proved designs suitable for Navy applications, and (4) significant storage and preprocessing of refuse fuel are not included in the decision model because of their yet uncertain costs on a small scale. Both fuel processing and storage are desirable, if they are justified.

BACKGROUND

The current emphasis on recycling [1] makes the use of solid waste attractive as a source of energy. Even where good fuels such as data processing cards are segregated for resale, there would still be considerable solid waste remaining with greater value as fuel than as components sold for direct recycling. Some refuse-fueled steam systems, even in the low capacity range down to 10 TPD (9 Mg/da), can accept solid wastes with minimum sorting and without mechanical preprocessing.

Escalating cost and uncertain availability of more conventional fuels, particularly natural gas and fuel oil are compelling reasons for implementing use of refuse fuel.

The Navy has been recycling solid waste in the form of steam energy since 1967 in the Norfolk Salvage Fuel Boiler Plant. This installation has demonstrated the effectiveness of waterwall/refuse-fuel boilers of relatively small size. There is, however, some size smaller than which these waterwall boilers are not justifiable. From the data presented in Figure 1, it is conservative to pick 50 TPD (45 Mg/da) as the capacity below which a waterwall system would be prohibitively expensive.



Systems

A. Single controlled air
B. Dual controlled air
C. 24-TPD rotary grate
D. 48-TPD rotary grate

Waterwall Refuse Fuel Plants

1. Norfolk NSY, Portsmouth, VA
2. Norfolk NS, Norfolk, VA
3. Harrisburg, PA
4. Nashville, TN (incl. distribution system)
5. Montreal
6. Saugus, MA
7. Braintree, MA
8. Akron, OH
9. Lexington, KY, (est)
□. Extrapolated from NAVFAC DM-3

Figure 1. Normalized capital costs for various systems as a function of system utilization or capacity.

The majority of Navy bases do not generate or have access to enough refuse fuel for a waterwall/boiler installation. At the Advanced Research Projects Agency (ARPA) workshop [2] there was a strong consensus against bases planning for acquisition and utilization of significant quantities of unprocessed refuse fuel from an adjacent community, even if it might be available. Current reports [3,4] indicate that it will be some time before an off-base supply of processed, refuse-derived fuel (RDF) would be available to any but a few bases. Consequently, this report assumes that most shore facilities can rely only on waste fuel generated internally or at other military activities within 10 to 20 miles (16 to 32 km).

Systems are currently available that can provide cost-effective waste-to-energy conversion in the 25-TPD (23 Mg/da) range. Notable among these are those with a rotary basket grate furnace. One such system has been in operation for over 4 years. Smaller, less expensive systems using a controlled-air furnace have been in operation for over 1 year. Based on manufacturers' data and military operation of controlled-air incinerators without heat recovery, a moderate program of development and testing will be required before controlled air furnace systems will be cost-effective in widespread military use for energy recovery.

All TPD figures in this report are based on a 5-day week. This is consistent with the refuse collection schedule at most bases. It is also consistent with the normal operation of solid waste systems which do not have any significant preprocessing or storage capability.

ECONOMIC DECISION MODEL

Description

The decision model comprises a set of graphs (Figures 2 through 8) that can be used for quick estimates of the profitability of heat-recovery incineration. The model is simple enough to be used with any solid-waste generation data available, even a crude estimate.

Figure 2 shows the effect of operating time of two typical systems, providing an indication of how the savings-to-investment ratio would vary for periods other than 7 years, a length of time used for calculating the data for Figures 3 through 8. Figure 3 provides for estimates of heating value and disposal cost savings, based on TPD generation rate. A detailed discussion of Figure 3 is given under ''Estimating Waste-to-Energy Benefits.'' Figure 4, calculated for one set of parameters, indicates which of the four systems (Figures 5 through 8) to consider; it shows the adverse economic effect of utilizing a system at considerably less than maximum capacity. Figures 5 through 8 provide estimates of the cost of owning and operating each of the four systems modeled for a 7-year period. The capital costs involved are based on 1975 prices.

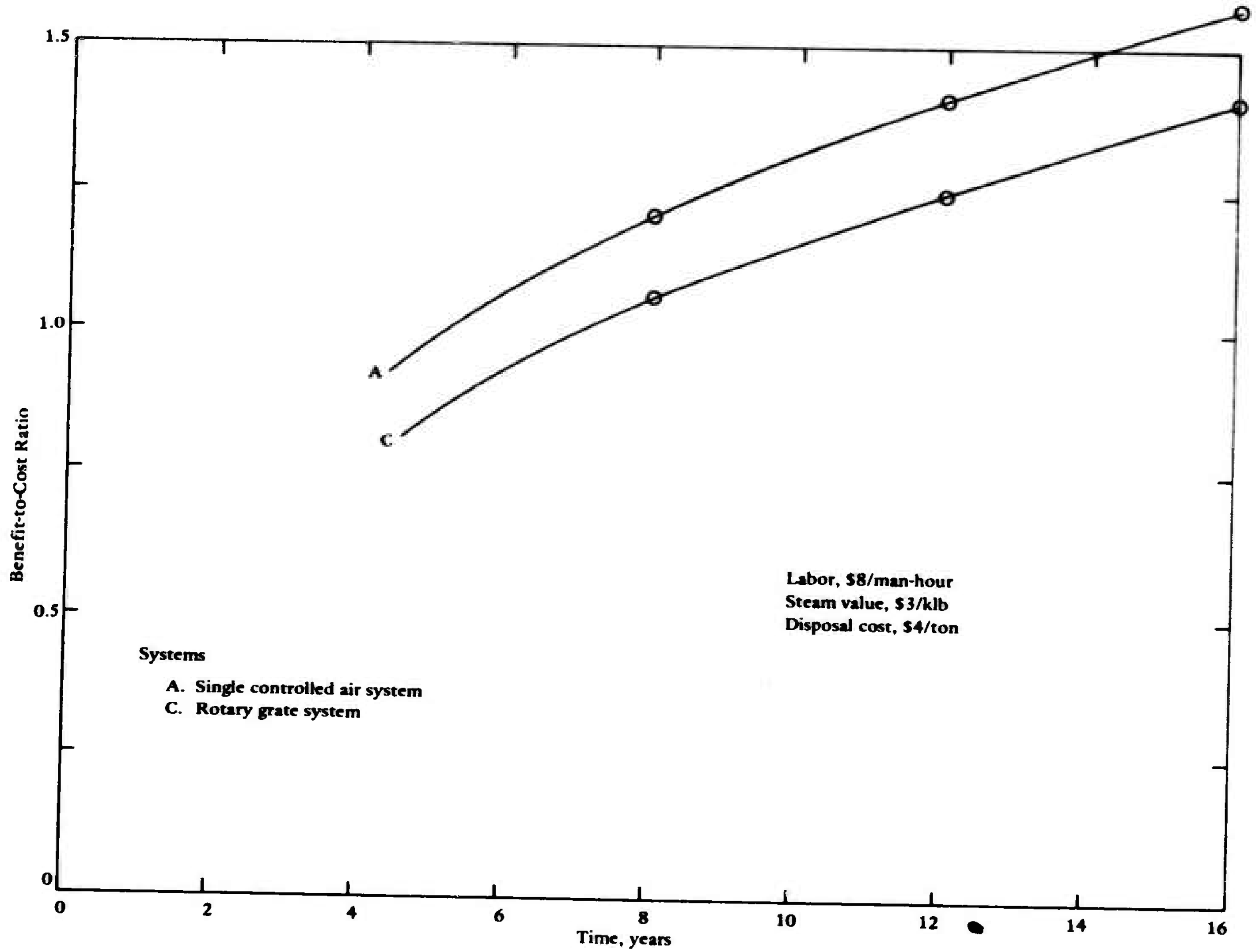


Figure 2. Effect of time on benefit-to-cost ratio for two system models at 20-TPD loading.

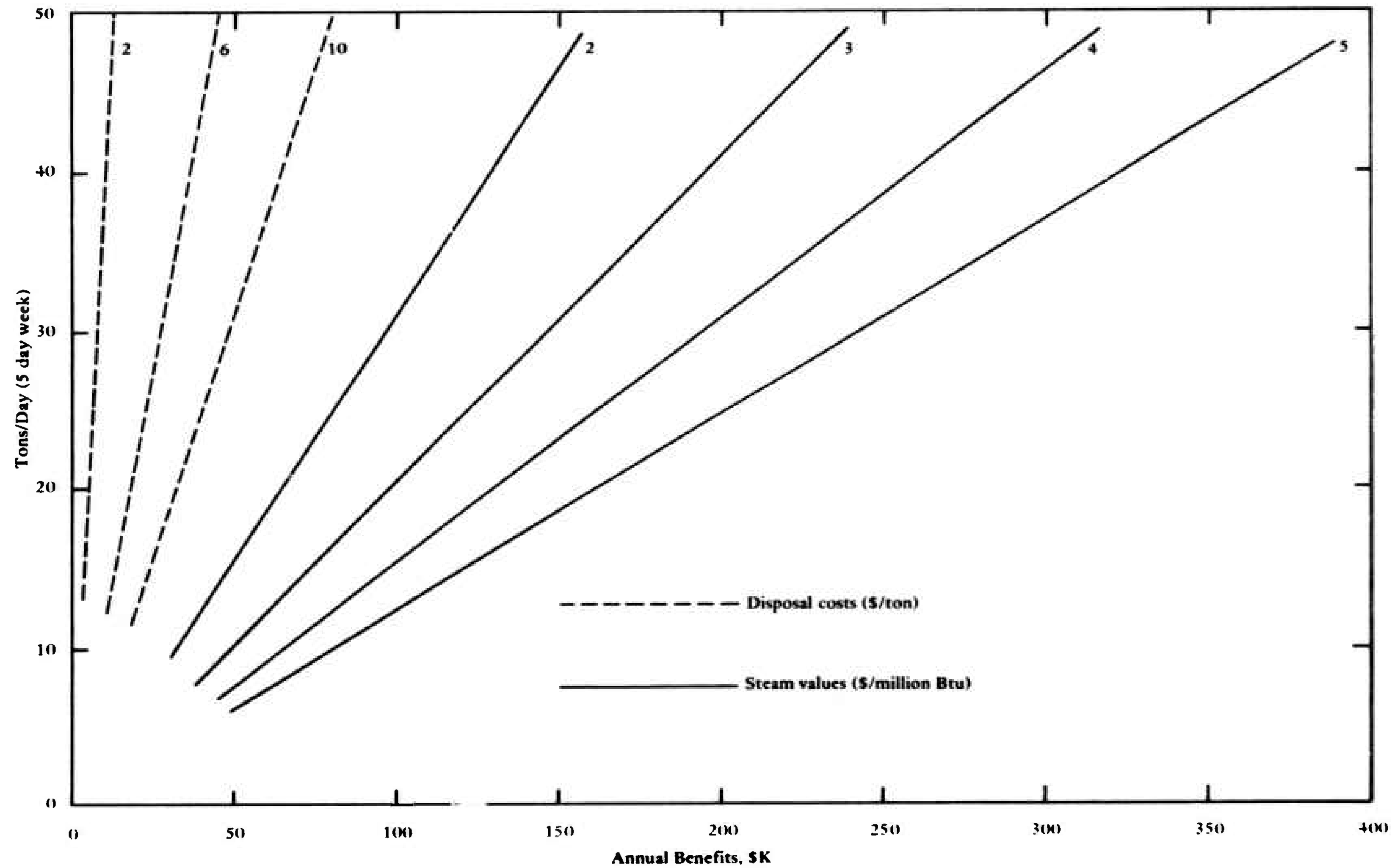


Figure 3. Average annual benefits for various disposal costs and steam values based on a 7-year period at 1975 dollars.

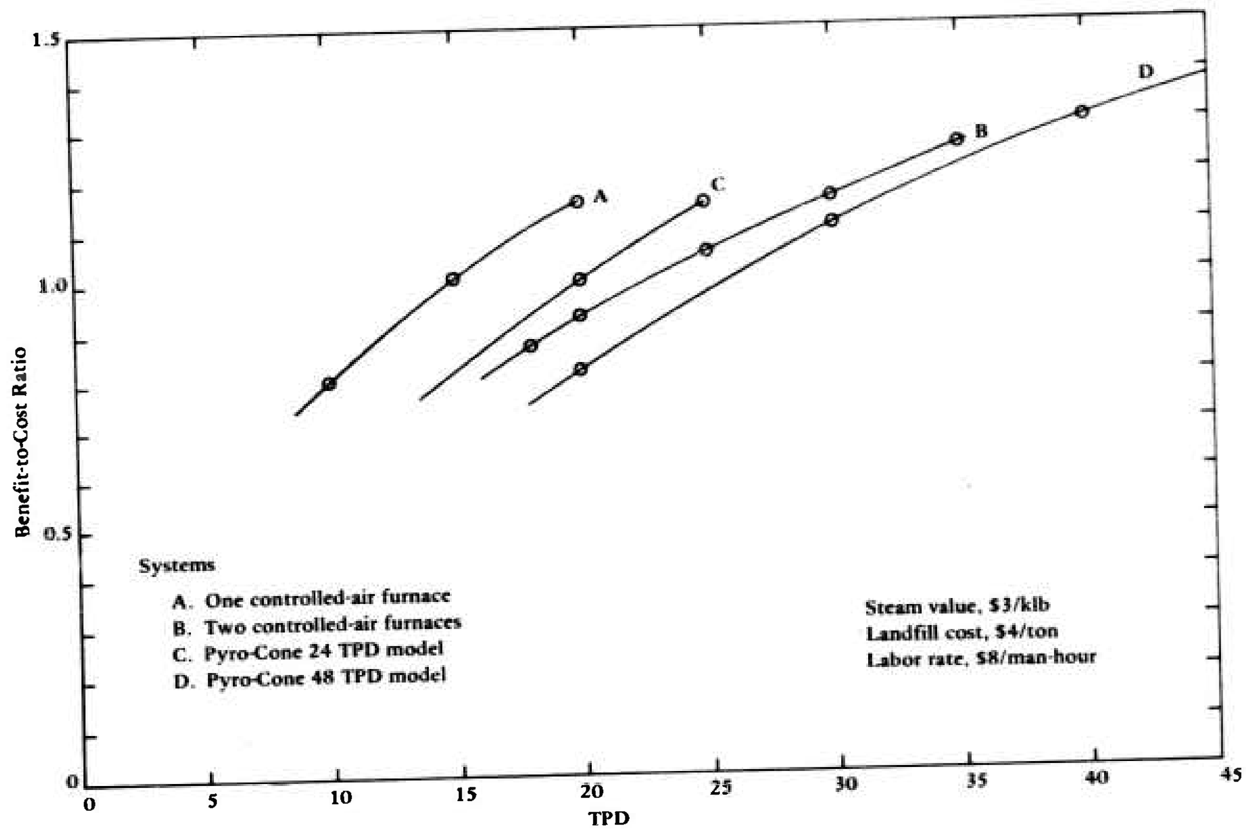


Figure 4. Benefit-to-cost ratios for four system models as a function of TPD utilization.

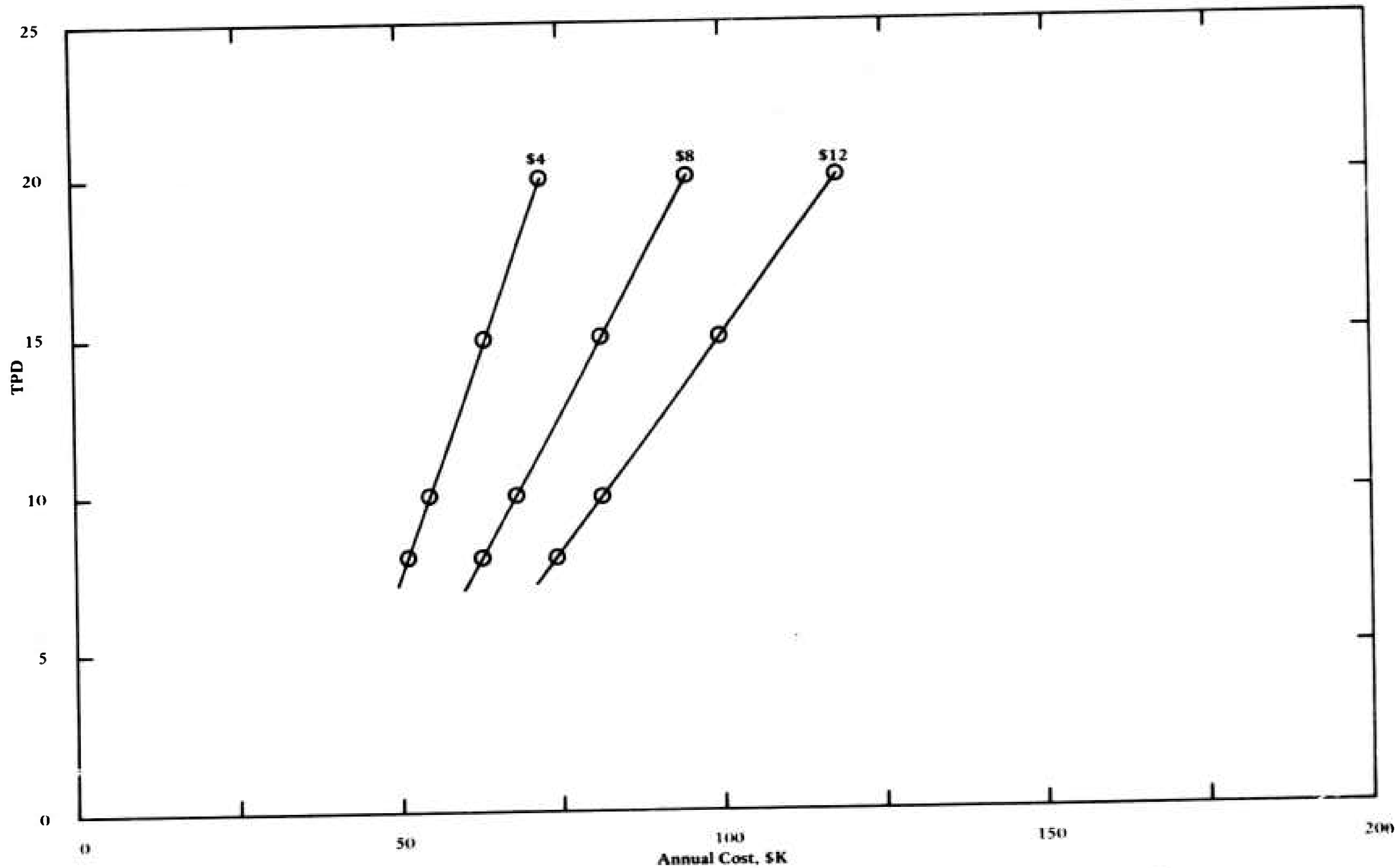


Figure 5. Annual cost for System A as a function of TPD loading and hourly labor rate.

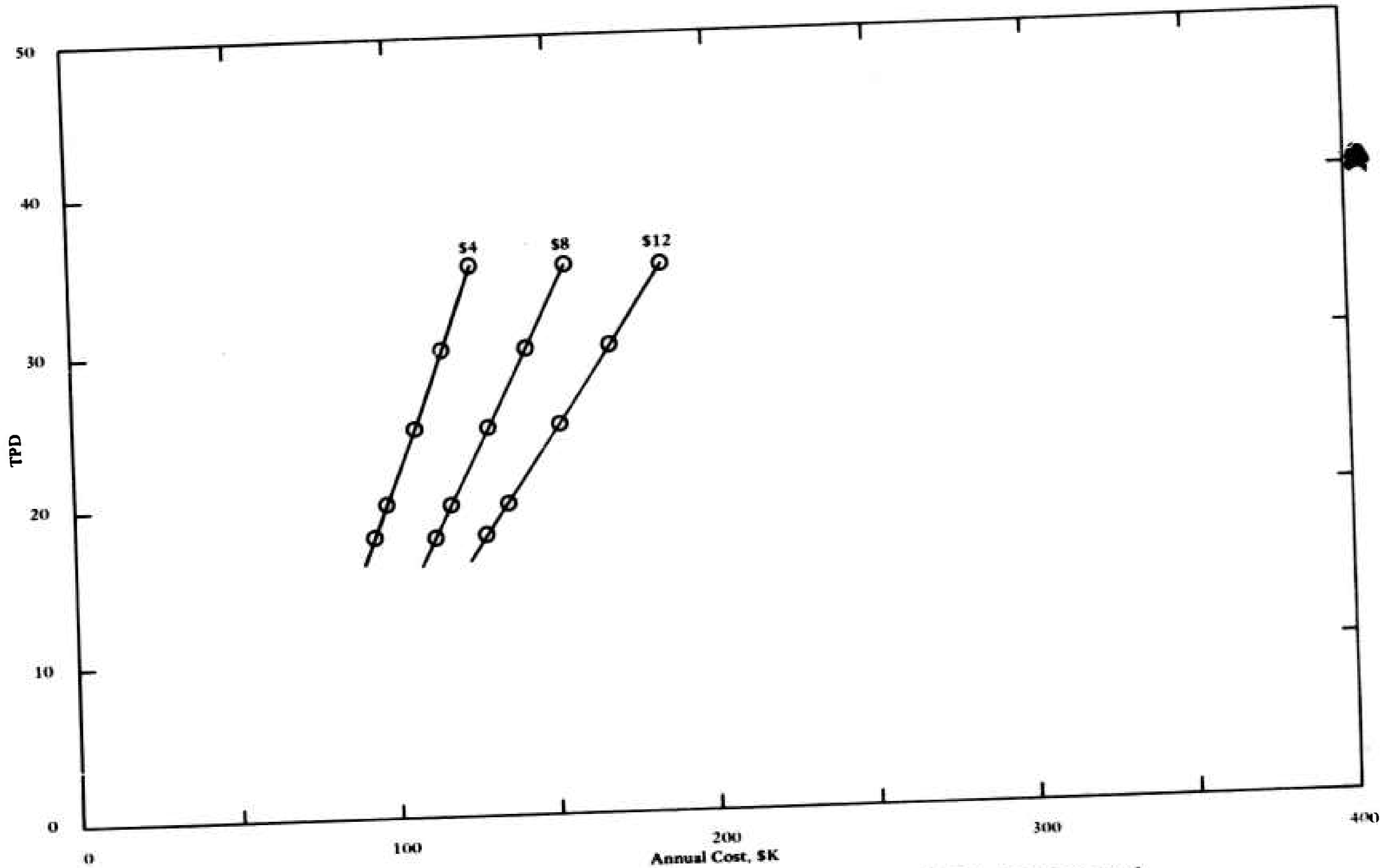


Figure 6. Annual cost for System B as a function of TPD loading and hourly labor rate.

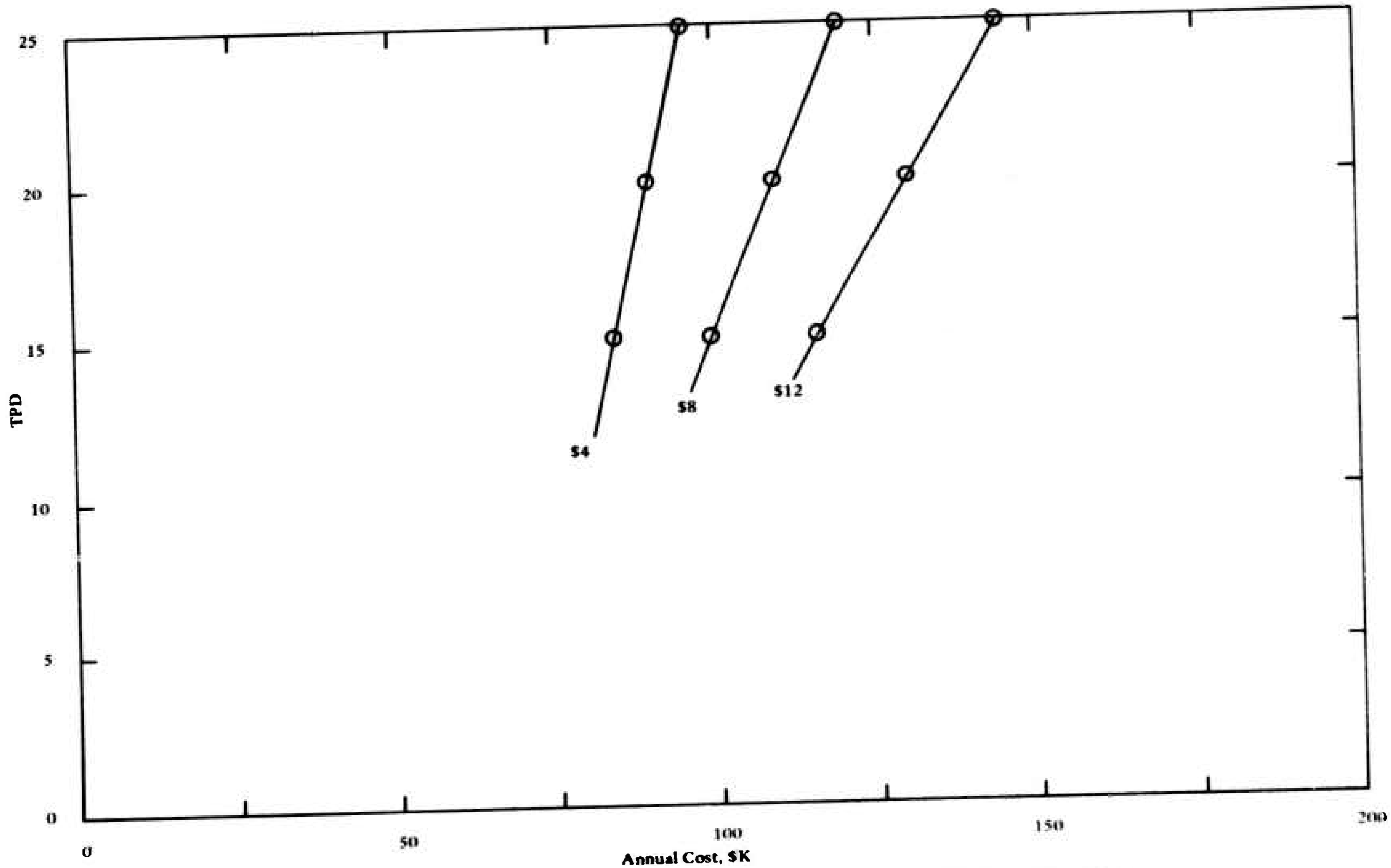


Figure 7. Annual cost for System C as a function of TPD loading and hourly labor rate.

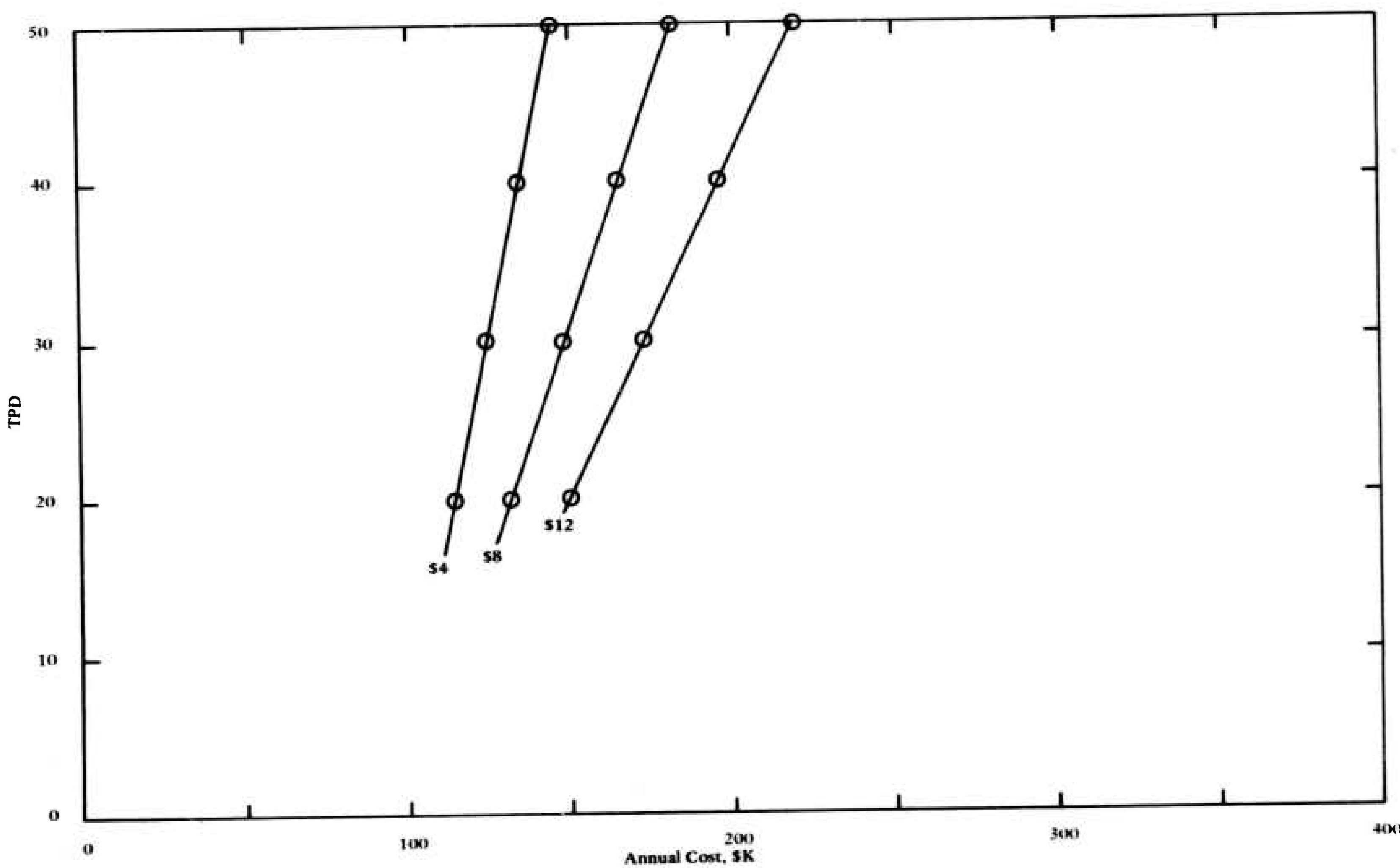


Figure 8. Annual cost for System D as a function of TPD loading and hourly labor rate.

Shorter than the expected economic lifetime of the equipment [5], the 7-year time for payoff of the capital investment is based on the combination of two principal factors: (1) the minimum number of years for which there is a high probability of payoff and (2) minimum uncertainty as to future inflation rates which affect the present values of both the benefits or savings and the operating cost or investment. Another lesser consideration in selecting the 7-year payoff period is the rapid rate at which air pollution regulations are becoming more stringent. A major modification to add additional air pollution control equipment several years from now could cost over half the original capital, as was demonstrated at Norfolk.

The decision model was designed for use at, or for evaluation of, a wide variety of individual military facilities. Several input parameters are required to accommodate differences in costs and practices at the various facilities.

The most critical input parameter is the generation rate in TPD of solid waste available as fuel. TPD is based on a 5-day-week, or a 260-day year. Comments on obtaining weight data, equivalent to part of a Phase B Survey under the R^4 Program are contained in Appendix A. It is strongly recommended that no further decision be based on this decision model unless generation data equivalent to that described in Appendix A are available.

Estimating Waste-to-Energy Benefits

With Figure 3, two benefits can be estimated that would accrue to any facility implementing conversion of solid waste to energy in the form of utility steam; i.e., reduction in disposal cost and value of steam produced. As can be seen, the value of the steam produced will invariably be the greater economic benefit.

Curves are presented for steam values between \$2 and \$5 per million Btu (\$2 and \$5/GJ). The model for steam value annual benefit is proportional to both TPD and steam value for accurate interpolation and extrapolation of this set of curves. These curves are based on a steam value inflation rate of 8.5% per year. A full description of all model parameters is contained in Appendix B.

The model analysis indicates that disposal cost savings will almost always be less than the economic benefit of steam generated. This results in part from double handling of part of the solid waste stream: (1) the ash and noncombustibles removed from the furnace and (2) the large noncombustibles sorted out and not loaded into the furnace. The curves for disposal cost savings present this benefit as a nonlinear function of disposal cost (\$/ton). This is because the model incorporates a \$1.50-per-ton (\$1.65/Mg) penalty for the double handling of the estimated 15% ash and noncombustibles.

It should be noted that disposal cost savings accrue only from that part of a facility's total disposal cost which is attributable to landfill operation or hauling off base. For most bases it is reasonable to

assume that costs of collection and hauling of solid waste within the base would remain about the same whether the waste is delivered to a recycling plant, landfilled, or trucked through the gate for off-base disposal. Any differences in on-base collection and hauling costs would either not be significant with respect to the other economic benefits or not be directly attributable to energy utilization. Consequently, if a facility's solid waste disposal cost is $50 per ton but only $6 per ton is attributable to landfill operation or off-base hauling, the disposal cost benefit would be determined from Figure 3 using the $6-per-ton line.

Other economic benefits could evolve at some facilities. For instance, a rotary grate furnace might satisfy requirements for routine or emergency destruction of classified material. In a moderate climate, heat from waste fuel might supply a sufficient percentage of the base load to slightly decrease maintenance costs on existing, conventional boilers. At most bases, however, steam energy from on-base waste fuel would provide for only about 10% of the load generated at the activity. This would normally make little or no difference in operating costs (excluding fuel) for the existing boilers. Additional benefits such as these, calculated on an annual basis for 7 years, could be added to the two benefits or savings figures from Figure 3.

Estimating Cost or Investment

Economic models for costs of four systems, covering capacity requirements from 10-to-50 TPD (9-to-45 Mg/da) are presented. These systems are similar in many respects; all are based on the following two criteria. First, producing the maximum amount of steam energy at the least possible cost is desired. Second, the system components must be as close as possible to current state-of-the-art. Analysis of the first criterion implies that the primary system components cannot be redundant for reliability and that the system will need to be operated 5 or more days per week, up to 24 hours per day. The first criterion eliminates waterwall salvage-fuel boiler plants from consideration (i.e., for capacities less than 50 TPD). Both criteria eliminate pyrolysis systems and fluidized-bed combustors from consideration in the stated size range. It should be noted that neither of the above criteria are necessarily valid for any particular base.

In developing the four system cost models it was assumed that unprocessed solid waste will be supplied directly to one or more heat-recovery incinerators within 24 hours of delivery to the incinerator site. Shredding of the refuse fuel prior to burning was not included in these analyses because of the uncertain cost and reliability of small shredders for mixed solid waste. However, if source segregation of solid waste were to be implemented at bases installing relatively small heat-recovery incinerators, then shredding of refuse fuel, from which metals, glass, and large objects have been removed, is expected to be beneficial. Under the solid waste program, CEL is currently evaluating source segregation, and shredders have been identified which appear suitable for small scale processing of a storable refuse-derived fuel from the combustible fraction of segregated refuse.

The individual system cost models, Figures 5 through 8, can be used in several different ways. The simplest way is to use TPD and local labor rate to determine an annual cost for a system. The sum of benefits obtained using Figure 3 can then be divided by the cost to find the benefit-to-cost ratio. This is the same as savings-to-investment ratio for an independent project as presented in Reference 5. If annual cost is taken equal to the sum of benefits previously calculated, Figures 5 through 8 can be used to determine TPD required for a 7-year break-even calculation, based on annual cost and local labor rate. Similarly, the labor rates* needed for a 7-year payoff of the system models can be determined using the cost which equals benefits and the available TPD of waste at a facility.

As can be seen from Figures 4 through 8, and as described in Appendix B, the four system models were designed for a broad spectrum of applicability. Therefore, they cannot account for differences in installation and startup costs which will vary regionally and even from base to base. All of the sytems are labor intensive as demonstrated by the spread of curves for the different labor rates in Figures 5 through 8. Variation in labor assignment and utilization practices is another potentially significant difference which would be very difficult to account for. Consequently, the results obtained from this decision model are approximations intended to be useful for making three possible decisions. The first, previously discussed, would be the decision to obtain accurate waste generation data. The second would be the decision to undertake a detailed analysis in accordance with Reference 5, if this model indicates a benefit-to-cost ratio near or exceeding 1.0, based on an accurate TPD figure. The third possible decision would be which systems or system components to consider.

Using the Model

A step-by-step procedure for the simplest use of the model is as follows:

1. Obtain an average TPD value for solid waste generation. If available generation information is based on volume, a density of 85 lb/cu yd (50 kg/m^3) is recommended for conversion to weight.

2. Entering Figure 3 with average TPD, move right to the appropriate local steam value and read steam value savings on the horizontal coordinate.

3. Re-entering Figure 3 with TPD, move right to the estimated local disposal cost attributable to on-base landfill operation or to off-base hauling and tipping fees only. Again read savings on the horizontal coordinate.

4. Add steam value savings, disposal savings, and any other annual savings which can be estimated for the individual situation.

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*It should be noted that the term ''labor rate'' as used in the above discussion is for cost-accounting: it is at least 1.3 times the hourly base pay for civilian direct labor.

5. Refer to Figure 4 to determine which systems have sufficient capacity and are potentially most profitable, based on average TPD for a 5-day week.

6. Enter Figures 5, 6, 7, or 8 for systems A, B, C, and D, respectively, with TPD. Move right to the appropriate labor rate for an incinerator/boiler system operator, and obtain annual cost from the horizontal coordinate. If peak daily collection data are available, a TPD figure equal to 85% of peak daily collection is suggested for use in estimating costs with the model.

7. Compare the sum of annual savings or benefits obtained in step 4 with each of the system costs. The magnitude of the differences of benefits over cost, as well as benefit-to-cost ratios and other local factors, may influence a decision for further evaluation.

COMPARISON OF TWO TYPES OF SYSTEMS

Rotary Basket Grate Furnace

Heat recovery systems using rotary basket grate furnaces are built by two companies in the United States: Ametek and Energy Conversion, Inc. (ECI). Figure 9 is a typical schematic diagram of such a system.

Ametek offers three sizes of furnaces/incinerators rated at 330-, 1,000-, and 2,000-pound per hour (150-, 450-, and 900-kg/hr) of type 1 waste. The two smaller sizes are considered too small for economical steam heat recovery systems. As of April 1975, Ametek intended to work on design improvements on the largest Model 1300/2000 which had shown some deformations of the grate basket.

An informal estimate for cost of an Ametek Model 1300/2000 system, with heat recovery as low pressure steam, was considerably higher than the price quotation for the ECI Pyro-Cone 24 TPD system. Consequently, system models C and D are based on the Pyro-Cone models 24 and 48, respectively. Table 1 presents data on the three ECI systems offered. The prices given include a hopper with nominal capacity of unprocessed waste for 8 hours system operation, backhoe, conveyor, furnace, boiler, baghouse filter for air pollution control, 50-foot (15-m) stack, induced draft fan, and control panel and components. The prices do not include wiring between components and fuel and hydraulic piping. Feed chute dimensions are given in Table 1, as an indication of the size of objects or items which would have to be broken up or sorted out of the waste fuel stream for each system. Figure 9 portrays a typical double gate, vertical feed chute. Figure 10, a photograph of a nearly assembled Pyro-Cone furnace, shows the feed chute above the furnace on the right and part of the cylindrical afterburner on the left.

Although the Pyro-Cone furnaces are now of standard design a system of any of these sizes could not be considered off-the-shelf. Some of the components, such as the refuse fuel storage hopper and the heat recovery section, can be tailored to an individual application. The manufacturer estimates a 1-1/2-year time lapse from award of a procurement contract until the system becomes operational.

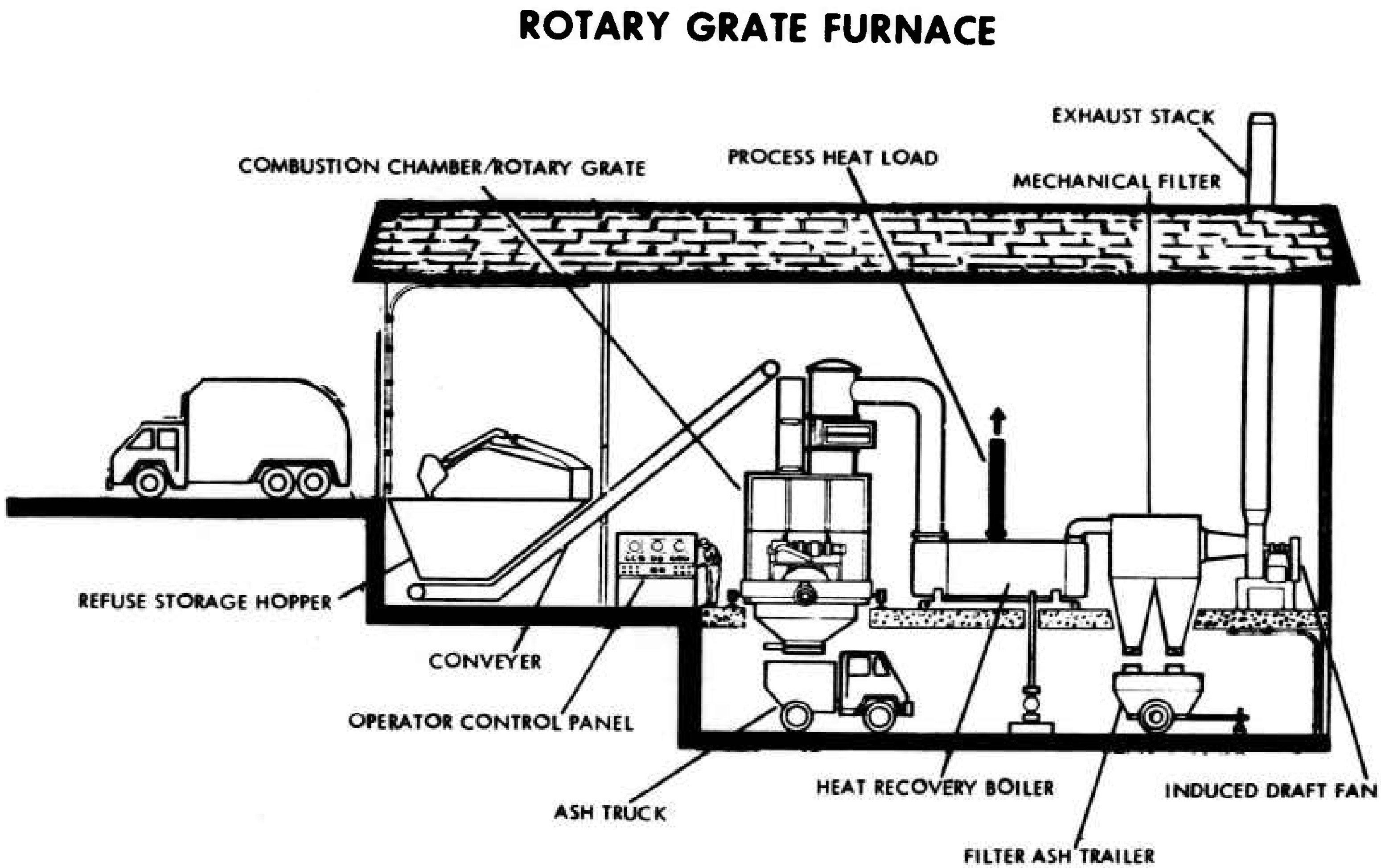

Figure 9. Schematic of current rotary grate system.

Table 1. Pyro-Cone System Data

Model/TPD Capacity	Component Cost, $K	Feed Chute Dimensions, Length x Width x Height (m)	Induced Draft Fan, hp (kW)
24	266	36 x 36 x 34 in. (0.9 x 0.9 x 0.9 m)	40 (30)
48	358	42 x 42 x 42 in. (1.1 x 1.1 x 1.1 m)	60 (45)
72	450	48 x 48 x 52 in. (1.2 x 1.2 x 1.3 m)	80 (60)

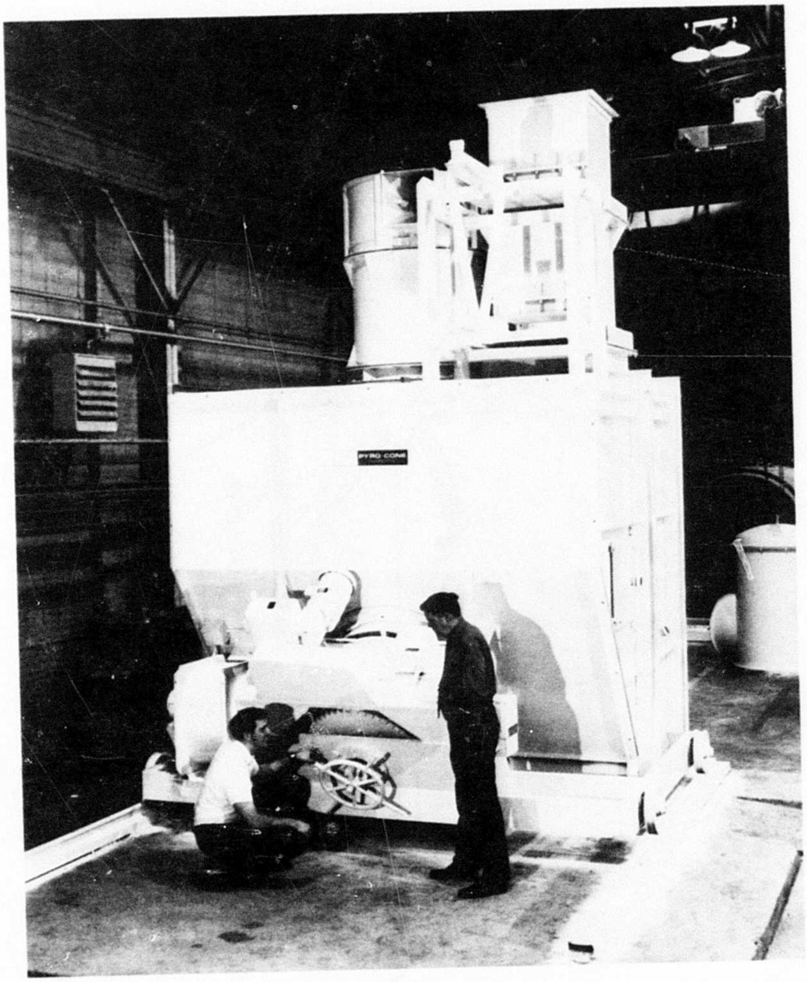

Figure 10. Pyro-Cone rotary grate furnace.

Controlled Air Furnace

The term ''controlled-air'' does not adequately characterize the systems to be discussed here. Virtually all modern waste-to-energy systems would incorporate precise control (or exclusion) of air supplies to various combustion or reaction zones. A clearer distinction from rotary grate and similar systems would be the lack of agitation or tumbling of the fuel bed in a controlled-air furnace.

Several manufacturers offer packaged heat recovery systems using controlled-air furnaces; other companies are interested in entering the field. These furnaces have almost all been developed from controlled-air incinerator designs, some of which were in operation in the 1960's. They have the following general characteristics:

1. Solid waste fuel is loaded into a grateless primary chamber.

2. Combustion air to the primary chamber is supplied and metered by a forced draft blower or other control devices. This amount of air is normally insufficient for complete oxidation of fuel loaded near rated capacity.

3. Emission of smoke and other incompletely oxidized products is controlled by an afterburner section which has an auxiliary fueled burner and provision for a supply of excess air. The afterburner is usually the only pollution control device, per se, installed.

4. Emission of inorganic flyash or particulates is controlled primarily by limiting the gas velocity through and above the fuel or ash bed in the primary chamber.

Although controlled-air systems are outgrowths of incinerator technology, most have had less than 1 year's operating history for energy recovery in the form of steam as of mid-1975. These systems lack refinements needed for implementing their operation at most military installations within the next 2 years. Some of the deficiencies have been well-documented [2,6,7,8]. Of primary concern is the reliability of continuous ash-removal subsystems. In addition, heat recovery efficiency (boiler efficiency) is low: 50 to 60% is commonly estimated. There is still a deficiency of data and analysis on savings-to-investment tradeoff for system insulation, primary chamber volume, and automatic controls. Estimates for auxiliary fuel consumption vary widely between manufacturers. Consequently, the two controlled-air system cost models, A with a single furnace and B with two furnaces, are not based on specific equipment.

Equipment costs for the A and B models were taken from the two lowest prices from experienced manufacturers for systems with a nominal capacity of about 1 ton per hour (0.9 Mg/hr). Other parameters and functions for the A and B models as listed in Appendix B are not necessarily conservative. To compensate, it was assumed that the maximum daily capacity for continuous operation of the controlled-air systems would be equivalent to only 18 to 20 hours loading at nominal capacity.

Controlled-air systems have two overriding advantages which justify continued interest in additional testing and development. First, they require a significantly lower capital investment than other low capacity systems. While the B curves in Figures 1 and 4 do not appear particularly spectacular, they do give an indication that a system using two controlled-air furnaces may fill a gap between other system model sizes. The A-system curves in Figures 1 and 4 are more significant. Even with a wide margin for error, these two curves demonstrate that controlled-air systems have a higher probability of paying off at waste fuel loadings below 20 TPD (18 Mg/da), than do rotary grate systems.

The second overriding advantage of controlled-air furnaces is simplicity. Excluding the continuous ash removal subsystems, these furnaces can be inherently reliable. Next to the ash removal subsystem, the most mechanically complex component is usually a ram loader. For over 5 years several manufacturers have been recommending and installing this type of loader for capacities over 500 lb/hr (227 kg/hr), so there is a good base of technology and operating history. A ram loader is usually more accessible than a chute loader for correcting a problem if it should occur. Other mechanisms and devices for moving the fuel/ash bed are not used in many models; movement in the ash/fuel bed usually occurs as new fuel is ram loaded. Other components of controlled-air furnaces (such as blowers, burners, and controls) should be of equivalent or greater simplicity compared to small tumbled-fuel systems.

In summary, controlled air systems have significant potential advantages of low cost and reliability, based on simplicity, for waste-to-energy conversion in the 10- to 25-TPD (9- to 23-Mg/da) range. Current disadvantages can be alleviated by a short-term development effort.

CONCLUSIONS

1. In the 23- to 50-TPD (21- to 45-Mg/da) utilization range, rotary grate systems currently exist that are suitable for energy utilization of solid waste at military bases and capable of payback in 7 years, based on realistic inflation rates and costs for some bases.

2. In the 10- to 25-TPD (9- to 23-Mg/da) utilization range, controlled-air systems offer the greatest potential for cost-effective utilization of solid waste as an energy source, after some current deficiencies are alleviated by moderate development effort.

3. To conserve conventional fuels by use of small waste-to-energy systems at the best possible savings-to-investment ratio, it will be necessary to give up redundancy of those major system components that might be desirable for reliability.

4. To achieve a short-term payoff of initial capital investment, semicontinuous operation of a waste-fuel system for a nominal 5-day week is desirable.

5. The large size of equipment currently required for acceptable reliability may make shredding too costly for incorporation in typical military solid-waste-to-energy systems in the 10- to 30-TPD (9- to 27-Mg/da) capacity range procured for operational use in the next 2 to 4 years.

RECOMMENDATIONS

The decision model presented here should be used as a basis for two possible decisions: first, to invest in a measurement and evaluation of on-base, solid-waste fuel generation as indicated in Appendix A; and, second, to perform a detailed economic analysis in accordance with Reference 5 at a particular base.

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Appendix A

COLLECTING SOLID WASTE GENERATION DATA BY WEIGHING

CERL found that all trucks carrying refuse must be weighed for at least 2 weeks to determine accurately the waste generation rate. By weighing trucks at the Naval Air Station (NAS) Patuxent River, MD [9], CERL determined a solid waste generation rate for this base of 19.8 TPD (18.0 Mg/da) with a standard deviation of approximately 5 TPD (4.5 Mg/da). Preliminary calculations for Patuxent River, based on a density of 200 lb/yd^3 (119 kg/m^3), has indicated a generation rate of 67 TPD (61 Mg/da). Other studies, including that reported in Reference 6 where refuse was weighed for months or years, have shown the maximum deviation of solid waste generation rate predicted by any 2-week period selected from the data base, as compared to the long-term data, was less than 5% (see article by H. G. Rigo, pp C1-C34 of Reference 2).

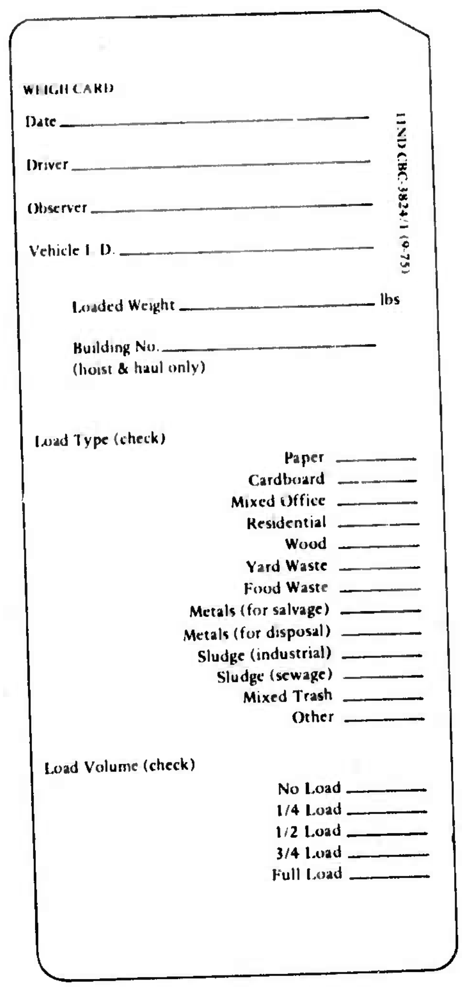
The common method of determining generation rate by counting trucks and applying a standard density can create large errors: (1) trucks may carry only partial loads, (2) compactor trucks will achieve variable compaction ratios, and (3) uncompacted density varies considerably from activity to activity and even within one such activity. Table A-1 shows this wide variation. Consequently, even if the volume of refuse generated by a base is known, it would be extremely difficult to predict the weight and heat content.

If a disposal site is on-base, all trucks delivering refuse can be weighed. Where solid waste is transported off-base for disposal, greater administrative control may be required to obtain weights for all nonroutine loads. In either case, an on-base or rented portable truck scale could be used. Also, in off-base disposal, an off-base scale may be available. A weigh card such as that shown in Figure A-1, however, should be filled out for each truck load of refuse delivered to the disposal site whether on- or off-base.

The data obtained by compiling and analyzing the information from weigh cards for two weeks or longer is important for several reasons. First, it gives an accurate figure for TPD generation rate. This in itself may be sufficient for estimating the available heat content of solid waste at typical bases where the overall average is within 10% of 6,000 Btu/lb (14 MJ/kg), as used in the decision model calculations. Second, however, the load type information on the weigh cards provides a good basis for adjusting the average Btu/lb figure up or down from typical norms at a particular activity. When an adjusted Btu/lb figure is determined for a base, the TPD figure used as a parameter in the decision model should be proportionately adjusted. Third, the weigh card information may point up a need for more extensive data collection or a need for changes in solid waste collection procedures if energy utilization of waste is to be implemented. Fourth, the weigh cards could indicate a potential ''high moisture content'' problem in some climates, which would influence the selection of a rotary grate system with a larger-than-normal auxiliary burner. Fifth, good volumetric data needed to determine size of a retention-and-handling area for unprocessed waste are obtained.

Table A-1. Density of Military Refuse [2,10]

Military Installation	Average Density, lb/yd^3 (kg/m^3)	Range of Density, lb/yd^3 (kg/m^3)
Atlanta Army Depot	25 (15)	-
Red River Army Depot	327 (194)	-
All Bases	84 (50)	21-327 (12-194)
Shipyards	-	117-202 (69-120)
Family Housing	-	100-300 (59-178)
Administration	82 (49)	-


WEIGH CARD

HND CBC 3824/1 (9-75)

Date ____

Driver ____

Observer ____

Vehicle I. D. ____

Loaded Weight ____ lbs

Building No. ____
(hoist & haul only)

Load Type (check)

Paper ____
Cardboard ____
Mixed Office ____
Residential ____
Wood ____
Yard Waste ____
Food Waste ____
Metals (for salvage) ____
Metals (for disposal) ____
Sludge (industrial) ____
Sludge (sewage) ____
Mixed Trash ____
Other ____

Load Volume (check)

No Load ____
1/4 Load ____
1/2 Load ____
3/4 Load ____
Full Load ____

Yellow Card

Figure A-1. Weigh card.

Appendix B

DECISION MODEL DESCRIPTION

The data presented in Figures 2 through 8 were obtained using a relatively simple program run on a time-sharing computer. This allowed quick and simple generation of cost and benefit values for many combinations of system functions, inflation or escalation parameters, and time. To convert recurring annual costs to present value, an exponential multiplier was used of the form

$$\frac{e^{(q-i)t}-1.0}{q-i}$$

where t = time, years

i = 0.10, annual interest rate [5]

q = annual inflation or escalation rate (Table B-1)

The decision model provides a spectrum of values for the significant variables - TPD, disposal cost, steam value, and labor rate - for insertion of local values. For less significant parameters, or parameters which could be established with a good degree of accuracy, values were set and used throughout the computations. These are listed in Table B-2.

The remaining parameters of the model are system functions. Of these, the most apparently significant is system efficiency, which directly and linearly affects the major benefit: quantity and, therefore, value of steam produced. To simplify presentation of the model graphs, a single benefit curve for all systems was calculated using an average efficiency of 60%. The individual system cost curves, Figures 5 through 8 were then adjusted to reflect the differences in system efficiency noted in Table B-3.

Table B-1. Inflation/Escalation Factors for Various Elements of Benefit and Cost

Element	q-value
Steam value	0.085
Landfill/disposal cost	0.05
Labor rate	0.05
Maintenance cost	0.05
Electrical power cost	0.03

Table B-2. Fixed Parameters and Values Assigned

Parameter	Value
Ratio: $\frac{\text{Btu/lb solid waste}}{\text{Btu/lb steam}}$	5.45
Days/year of system operation	260
Present cost of electricity, \$/hp-hr	0.02
Current disposal cost saved because of decreased tonnage, %	75%
Weight of waste stream requiring disposal (ash and rejects), %	15%
Penalty assessed for double handling of above 15%, \$/ton	1.50

Table B-3. System Model, Capacity Ranges, Functions, and Function Value Ranges

System Function	Function	Minimum Value	Maximum Value
A. Single Controlled Air System		8 TPD	20 TPD
1. Capital*	\$160K + \$4K x TPD	\$192K	\$240K
2. Annual maintenance, % of capital	5%		
3. Operating man-hours/day	4 + TPD	12	24
4. Efficiency	55%		
5. Horsepower-hr/day	400		
B. Dual Controlled Air System		18 TPD	35 TPD
1. Capital*	\$280K + \$5K x TPD	\$370K	\$455
2. Annual Maintenance, % of capital	5%		
3. Operating man-hours/day	4 + 0.8 x TPD	18.4	32
4. Efficiency	55%		
5. Horsepower-hr/day	800		

Table B-3. (continued)

System Function	Function	Minimum Value	Maximum Value
C. Pyro-Cone 24 (Rotary Grate) System		15 TPD	25 TPD
1. Capital*	\$310K + \$2K x TPD	\$340K	\$360K
2. Annual maintenance, % of capital	6%		
3. Operating man-hours/day	5 + TPD	20	30
4. Efficiency	65%		
5. Horsepower-hr/day	1,500		
D. Pyro-Cone 48 (Rotary Grate) System		20 TPD	50 TPD
1. Capital*	\$450K + \$2K x TPD	\$490K	\$550K
2. Annual maintenance, % of capital	6%		
3. Operating man-hours/day	6 + 0.8 x TPD	22	46
4. Efficiency	65%		
5. Horsepower-hr/day	2,200		

*Includes allowances for building construction and component installation.

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